

A three-dimensional view of charging infrastructure equity

SEI policy paper
June 2022

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Layout: Richard Clay
Cover photo: © Magnus Johansson / flickr

DOI: 10.51414/sei2022.020

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Contents

Sweden as a case study	5
Insufficient data on private charging infrastructure deployment	6
Comparing access to private charging around Sweden	6
Starting from the top.....	7
Comparing Swedish cities	8
Taking a closer look at the postcode level.....	9
Flexible charging means equitable charging	11
Conclusions	11
Acknowledgements	12
References	13

Key messages

- Three dimensions to charging infrastructure equity are explored, using Sweden as an example: data on private charger deployment, access to charging infrastructure, and the role that private charging plays when it comes to demand flexibility.
 - Car density has an inverse relationship to charger density: the higher the number of cars per capita in a given area, the lower the number of chargers. Disposable income has a direct one in most cases analysed: the higher the disposable income, the higher the number of chargers per capita in a given area.
 - Cities where overall mean private charger density is above the national mean still have a significant share of areas with charger density below that mean, signifying the need to collect data at the most local level.
 - Private charging, e.g. at home or work, should be the main charging strategy because it delivers time-flexible charging at lower costs. Public charging, although important, cannot and should not be the main metric for infrastructure equity.
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Electric vehicle (EV) sales are on the rise, as plug-in hybrid and battery electric cars become more affordable and reasonable for lower-income people. One key to this transition is also making the fuel that powers them more accessible – electric charging stations and other infrastructure must be affordable, available and in close proximity to where they are most needed.

Previous studies show that EV owners are likely to be wealthier and more educated, and that poorer and less educated populations may have less access to public charging infrastructure, which seemingly would support EV ownership (Fevang et al., 2021; Hsu & Fingerma, 2021). Studies are lacking with a focus on access disparities related to private charging.

If a transition to fossil-free alternatives for transportation is to help reach climate goals, it must be implemented in a manner that does not exacerbate existing inequalities, in terms of accessibility to services, as well as personal and household mobility costs. Here, we use Sweden as an example to introduce three dimensions that are linked to equitable charging infrastructure deployment, with a focus on private chargers: data transparency, local accessibility and opportunities for demand flexibility.

Using these three dimensions, we present an overarching analysis of charger subsidy schemes at the national level and local level. Our analysis shows that private chargers (including at-home and at-work charging) appear in higher density in Swedish urban areas with higher incomes; however, car density is much higher in other parts of the country, where private charging access is still low.

Based on our analysis, we make specific recommendations for data collection and for developing indicators for monitoring access to private charging infrastructure and its relationship to income inequalities at the most local level. These measures will bring us closer to broader infrastructure deployment, and as a result, EV expansion will occur more quickly on the path to fossil-free transport.

Sweden as a case study

Global sales of EVs represented 10% of all global car sales in 2021 (IEA, 2022). Sweden currently has about 320 000 EVs, equal to 6% of the passenger car fleet; of these, 37% are battery electric and 63% plug-in hybrids.

By 2030, estimates put the total of EVs in Sweden at 2.5 million. The country currently has 14 339 public charging points – a 438% increase compared to the 2664 points installed a mere five years ago (Powercircle, 2022). The number of private charging stations is currently unknown.

The European Commission defines public chargers as “all recharging points that provide open, non-discriminatory access and therefore include recharging points on private grounds if those grounds are accessible to the public, including for example supermarkets, shopping malls, parking lots, etc.” (European Commission, 2021). The use of private chargers, on the other hand, is restricted, e.g. for home charging or charging in private garages and workplace parking.

A strategy to promote EV adoption is government funding of charging infrastructure, both public and private. However, barriers to infrastructure access could be hampering EV growth. In Sweden, for example, the Swedish Energy Agency previously focused on barriers to private charging access (Energimyndigheten, 2021). And the Swedish Environmental Protection Agency (EPA) investigated how unequal infrastructure access across the country could intensify mobility inequalities (Ek & Wårell, 2021).

Swedish journalists have also investigated funding and concluded that the biggest municipalities and tourist destinations have received the most subsidies for establishing private charging infrastructure (Arnsäter, 2022). Meanwhile remote areas, especially in northern Sweden, have shown limited interest and used only a small part of funds available for establishing private or public charging (SVT, 2022).

Differences in access to public transport and in population density imply that transformation costs differ between municipalities in their push for fossil-free infrastructure. As highlighted by the Swedish EPA study (Ek & Wårell, 2021), the lowest costs are in Stockholm, the municipality with highest population density, and the highest costs are in Gislaved and Arvidsjaur, which are municipalities in low-population regions in the south and north, respectively.

The Swedish EPA study results also show significant differences in transformation costs for people who live in rural municipalities in sparsely populated areas and in central parts of cities that are densely populated and have little space. Households in central parts of cities have lower transformation costs to become fossil-free: they can more easily switch to sustainable transport modes, as distances are generally shorter, and the range of public transport options is more developed. Support for the transformation costs of electrification of transport is more important for small municipalities with small populations and long distances, where the conditions for public transport are limited and individuals must pay more for their own transport or household fossil-free transformation.

We raise these aspects of the transition above to contribute towards a greater understanding of how to design solutions that ensure increasing equity in the EV market. Equity is key so that the benefits of electrification are experienced by all. Barriers that are universal include the cost of purchase and the range of EVs, but infrastructure access is one barrier that varies and can be addressed locally.

As Hardman et al. (2021) pointed out, installing public infrastructure alone is not the same as providing access to charging in low-income communities. Data can provide a more nuanced understanding of charging infrastructure deployment, local charging access variations, and potential opportunities charging demand flexibility can offer. Using the available data, we provide a view of the structural gaps and variables influencing the decision to purchase and transition to non-fossil fuel modes of transportation, of which EVs are one option.

Insufficient data on private charging infrastructure deployment

Data completeness and transparency are key barriers to getting a more detailed understanding of how EV chargers are deployed. Without access to the data, policy makers cannot make informed decisions on types of support and targets to set for EV expansion.

Most targets for charging infrastructure deployment cover only public charging because there are no official data on private charger deployment. For example, the European Alternative Fuels Infrastructure Regulation has targets only dedicated to public charging, even though private charging is acknowledged as the dominant charging strategy due to longer parking times at private charging locations (European Commission, 2021).

Focussing on public charging infrastructure as the major Key Performance Indicator (KPI) of infrastructure roll-out “success” is contradictory. A cornerstone of any analysis involving charging strategies for increasing EV deployment includes an assumption that the major share of charging will take place at private locations, mainly at a home or at an office. This share of private home charging has been previously estimated to be 50% to 80% (Hardman et al., 2018).

Sweden, for example, has no official data on private chargers, their location and capacity – in other words, no data on private charging infrastructure. Planning is made based on the assumption that potential EV owners will arrange to have some access to private charging, either themselves (if they own their house or apartment), through their housing association (if they are members of one), or their employer (in the case where EV chargers are offered at work parking spaces). As we show below, this assumption is not always accurate.

Comparing access to private charging around Sweden

Without the private charger information layer, how can we assess progress, fairness and policy gaps in overall EV charging infrastructure? For an initial picture of how private charging deployment looks, we used data on the distribution of applications for the non-public charger purchase subsidy schemes that have been administered by the Swedish EPA. The subsidies are not differentiated by income, and applications could be sent via post or e-mail. Regional authorities and municipalities offered support and spread information through communication campaigns, such as the “Fixa Laddplats” (in English, “Get a Charger”) campaign.

A scheme called “Ladda Hemma” (“Charge at Home”) targets individual homeowners, while another is called “Ladda Bilen” (“Charge the Car”) and is aimed at housing associations, organizations and companies that want to install chargers for private use by apartment residents or employees, and when needed, visitors. The support does not exceed 50% of the purchase price and does not exceed 15 000 SEK per charger. The “Ladda Hemma” program was replaced by an equivalent tax exemption in January 2021.

The dataset includes 69 534 anonymized charging point applications organized by postcode, where individual homeowners applied for slightly more than half and housing associations, companies and other organizations applied for slightly less than half (see Table 1). We assumed that the number of applications equals the actual total number of private charging points.

We removed outliers from the dataset and integrated it with sociodemographic data at the postcode level, such as disposable income, number of residents, and private car ownership (SEI, 2019). The population of each postcode polygon is used for calculating private charger and private car density.

Table 1. Information about the Ladda Hemma and Ladda Bilen support schemes.

Subsidy scheme	Time period	Number of applications	Number of charging points
Ladda Hemma: for individual homeowners	May 2018 – November 2021	35 183	35 183
Ladda Bilen: for housing associations, organizations, and companies	March 2020 – November 2021	5215	34 351

Source: personal communication and data supplied by Naturvårdsverket, 2021.

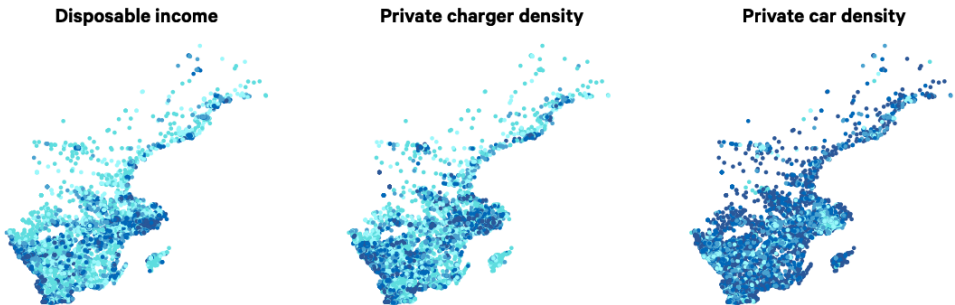
Starting from the top

Geospatial trends for the whole of Sweden are shown in Figure 1. Disposable income and private charger density seem to follow very similar patterns: more private chargers exist where the mean disposable income is higher. This pattern occurs in more densely populated urban areas, e.g. Stockholm, Gothenburg or Malmö.

However, car density seems to follow the opposite trend: fewer cars per capita occur where the mean disposable income is higher. This can be attributed to the higher income levels in urban centres, which also have higher population density and better access to public transport.

The three variables we examined – disposable income, private charger density and private car density – are linked to population density: the first two positively and the last, negatively.

Figure 1. Swedish postcode-level distribution of disposable income (SEK/capita), private charger density (chargers/capita) as estimated from Swedish EPA applications, private car density (cars/capita). The data points are classified in quantiles ($q = 5$), with the darkest colour (blue) representing the highest quantile.



Source: SEI analysis of data supplied by Insight One (disposable income and car density at postcode level) and Naturvårdsverket (private charger applications), personal communication, 2021.

OBSERVATION 1:

Private chargers appear in higher density in urban areas with higher income levels. Given that EV expansion and infrastructure deployment happens first in cities, this is unsurprising but still contradictory to where cars are more densely located, and where infrastructure would eventually be needed if transport is electrified.

Comparing Swedish cities

We compared nine Swedish cities: the top three cities in population (Stockholm, Gothenburg, Malmö), smaller cities in the north (Umeå, Kiruna, Östersund) and central Sweden (Jönköping, Karlstad), and the island municipality of Gotland. Table 2 shows how the mean disposable income, private charger density, and car density for these cities compare to the national mean for these values. The national mean is calculated as the overall mean for all Swedish postcodes.

The comparison shows that the three major cities (Stockholm, Gothenburg, Malmö), Umeå and Östersund have a private charger density that is above the national mean. Looking at the other cities, Kiruna in the north has a mean private charger density that is 93% lower than the national mean, followed by the island of Gotland, which is -83% of the national mean.

However, car density in the three biggest cities is considerably lower than the national mean. In other words, these cities have less dense car ownership but have charger densities that are higher compared to the national mean or even compared to other cities. Should we assume that the bigger the city, the less the problems are with charging infrastructure access? Or should we assume that car density is not a good predictor for charger density and income might be a better option?

Table 2: Difference of the mean disposable income (SEK/capita), private charger density (chargers/capita), and private car density (cars/capita) of nine Swedish cities to the national mean. Data are originally at postcode level and then aggregated to the municipality level. The municipalities are sorted by population (from largest to smallest).

Municipality by population	Comparison of the national mean to all Swedish postcodes		
	Mean disposable income (SEK/capita)	Mean private charger density (chargers/capita)	Mean private car density (cars/capita)
Stockholm	45%	43%	-38%
Gothenburg	7%	58%	-25%
Malmö	-5%	8%	-18%
Jönköping	-2%	-8%	-3%
Umeå	-3%	27%	0%
Karlstad	3%	0%	8%
Östersund	-2%	18%	7%
Gotland	-17%	-83%	25%
Kiruna	-5%	-93%	11%
National mean	167 592	0.02	0.31

Source: SEI analysis of data supplied by Insight One (disposable income and car density at postcode level) and Naturvårdsverket (private charger applications), personal communication, 2021.

OBSERVATION 2:

Private charger density across selected Swedish cities varies a lot. Car density has an inverse relationship to charger density. Drawing conclusions is more challenging when it comes to the relationship of disposable income to charger density, which is sometimes directly and other times inversely proportional to charger density, which means that other factors might come to play, e.g. population density.

Taking a closer look at the postcode level

Is there equal access to private charging in the cities we examined? Analysing private charger applications at postcode level, we observed variations compared to the aggregated mean. Even in cities with estimated charger density above the national mean (see Table 2), specific areas have values below the national mean (see Figure 2). Gothenburg's mean private charger density is 58% above the national mean, for example (see Table 2), but 69% of the postcodes within the municipality have charger densities below the national mean. Similarly for Stockholm and Umeå, 71% and 77% respectively of postcodes are below the national mean. Higher concentration of chargers per capita might appear in larger housing associations or work parking spaces, which could account for these differences, but the data are missing.

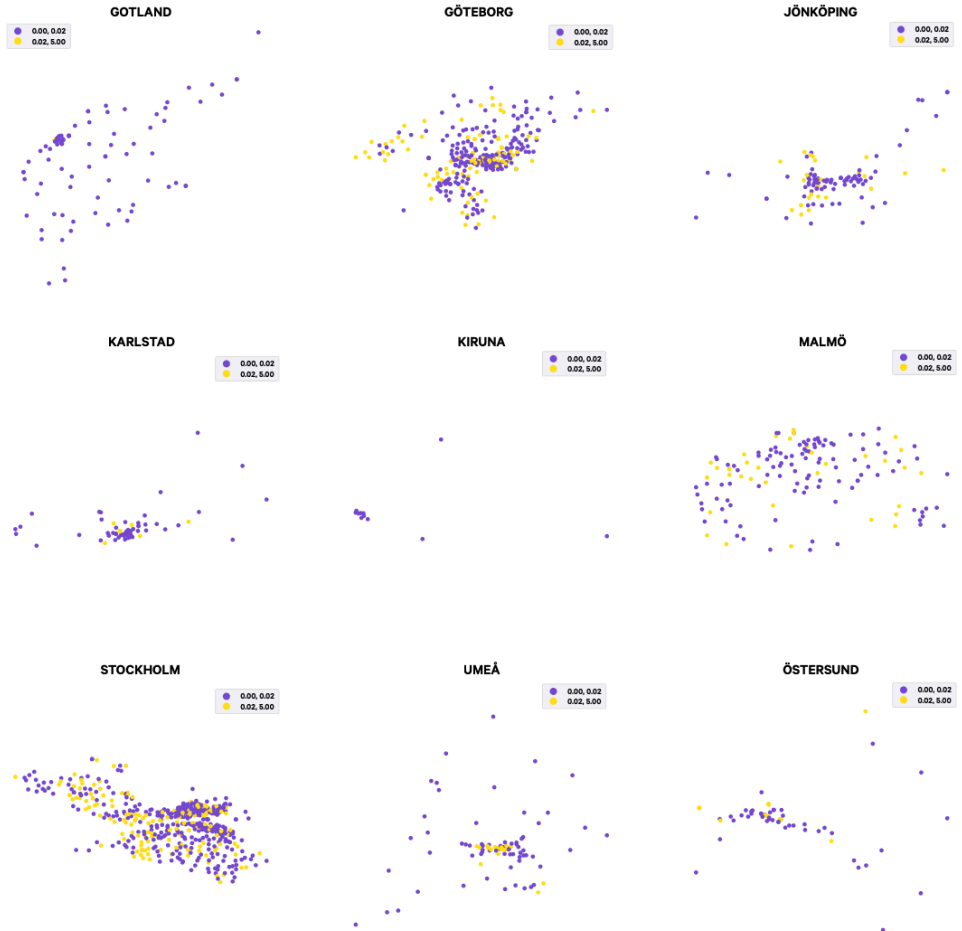
OBSERVATION 3:

A richer level of information regarding charger deployment is available if we look at postcode level. Cities where the overall mean private charger density is above the national mean still have a significant share of areas with charger density below it.

Potential reasons for the differences in private charger densities estimated between and within Swedish cities could be the following:

- **Income variations:** previous research has demonstrated the impact of income on EV purchases (Fevang et al., 2021). When EV purchasers also purchase chargers, then income could be a major factor affecting private charger deployment.
- **Neighbourhood effect:** peer influence on household energy behaviours, including the example of EVs, has been documented in previous research (Wolske et al., 2020). Neighbourhoods with early EV adopters that have navigated the charger purchase system might have an advantage for further expanding private charger deployment.
- **Housing conditions:** the Swedish Energy Agency highlighted that lack of charging access due to split incentives between landlords and renters hinders EV uptake (Energimyndigheten, 2021). Population density and lack of access to parking spaces are other influential factors; charger installation may be easier for single-family homes, for example (Hall & Lutsey, 2020).
- **Geographic variations:** transition costs are higher for rural areas compared to urban centres that have better access to public transport and shorter travel distances. Access to charging is particularly important for less dense municipalities, since there are limited mobility options beyond cars (Ek & Wårell, 2021). High market risks might mean that private charging is the only available option, but lower income and lack of information can be major barriers.

Figure 2: Comparing private charger density (chargers/capita) estimated from Swedish EPA applications at postcode level. The data points are classified with the darkest colour representing values below and the lighter above the estimated national mean private charger density (purple is below and yellow is above).



Source: SEI analysis of data supplied by Naturvårdsverket (private charger applications), personal communication, 2021.

Flexible charging means equitable charging

Access to charging needs to be flexible in order to be equitable. We consider flexible charging overall to be a combination of private and public infrastructure, dictated by local conditions. Generally, longer parking times make private charging important for the electricity grid. The longer a car is expected to be parked at a location, the larger the potential for flexible “smart” charging, by shifting electricity loads throughout the day.

Such flexibility is beneficial from multiple perspectives. From a grid perspective, peak loads can be reduced and additional grid investments avoided. From a car owner perspective, charging costs can be lower when charging is done when electricity prices are the lowest. From a climate perspective, optimizing charging to the electricity mix can lead to higher renewable energy source utilization and could stimulate additional investments in wind or solar, for example, for covering increasing demand.

Thus, EVs are a means to provide flexibility to electricity grids, integrate renewable energy sources to a higher extent, and decrease “fuel” costs for households. Removing this flexibility removes a part of the benefits of EV introduction in our energy and transport systems.

The available time to charge is key to flexible integration of EVs in a more renewable-based electricity grid: the more time available, the more flexible can charging be. The majority of flexible charging should be expected to happen at home or the office. Public charging, on the other hand, represents a smaller share of charging sessions (5% according to previous studies; Hardman et al., 2018). Although public charging is critical for curbing range anxiety and linking to real-world driving patterns and everyday routines (Hardman et al., 2018), previous research has concluded that public charging can be seen as a necessary alternative to private charging only in some densely populated areas (Funke et al., 2019). In any case, its degree of importance is very much affected by local conditions (Funke et al., 2019).

Additionally, public charging is associated with higher prices due to the generally shorter charging session duration and high power needs. According to data from Swedish charging providers, estimated costs of slow charging at home are 1.5 SEK/kWh (Vattenfall, 2022), while slow charging at, for example, a fuel station, costs 117% more (3.5 SEK/kWh), and fast charging (150 kW) costs 299% more (5.99 SEK/kWh; OKQ8, 2022). Owning an EV should not be a luxury in a society that wants to make a fossil-free transition; access to cheap, flexible private charging is necessary to make that transition.

Conclusions

Among the various barriers to EV adoption, access to charging infrastructure is among the most localized and sensitive to demographic variations. We examined how existing demographic inequities are being exacerbated or new structural inequities added to the transition to EVs, via lack of data, unequal access and distributive as well as procedural barriers in place, using Sweden as a case study.

We recommend more systematic data collection and curation for private charging infrastructure at national and local levels. The Swedish Energy Agency has acknowledged this data gap and is coordinating efforts with other public agencies (Energimyndigheten, 2021). Furthermore, municipalities need to develop indicators for monitoring access to private charging infrastructure and its relation to structural inequalities at the most local level (i.e. postcode level or equivalent), since our insights show that only measuring at the municipality level might fail to capture significant differences. Targeted efforts could support the roll-out of charging infrastructure; charger cost-sharing as an investment risk minimizing option may be one of the policy instruments worth considering for some municipalities.

Furthermore, investing in infrastructure for alternative modes of transport is also an important tool to reduce driving. Such measures include improved infrastructure for pedestrians and cyclists, which can increase comfort and safety with walking and cycling paths. Measures that make car journeys more expensive, such as congestion taxes, higher fuel taxes or higher parking fees, also make these more active modes of transport relatively more attractive.

We can see from our data as well as from complementary studies undertaken in Sweden (Swedish EPA) and elsewhere that it is easier for households living in central parts of cities to switch to sustainable transport modes, as distances are generally shorter, and the range of public transport is more developed. These include walking and cycling, as well as public transit options.

Deeper analysis is necessary to pinpoint the underlying reasons for the discrepancies we found using an equity lens. Public charging is important, and we suggest further analysis for the case of Sweden, but the majority of charging still needs to happen privately.

Regardless of the type of charging considered, access to infrastructure for charging EVs needs to be available throughout Sweden and any other country or region hoping to move away from fossil fuels. The expansion of such infrastructure mainly takes place in privileged metropolitan areas today, which is problematic. We see room for more clearly targeted government instruments for this infrastructure to be developed even in small municipalities with few alternatives to cars, as well as less privileged areas in larger municipalities.

Acknowledgements

This research is part of the ongoing project “Governing a fair transition to a fossil-free welfare society”, which is funded by FORMAS, the Swedish Research Council for Sustainable Development. The results presented are preliminary, as we continue with data analysis and will publish results in full.

We thank Naturvårdsverket, the Swedish Environmental Protection Agency and InsightOne for provision of data on private charger applications and sociodemographic variables, respectively. The authors have no conflicts of interest.

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